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ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Water Table Characteristics under Tamarisk in Arizona

Howard L. Gary and C. J. Campbell[1]

Describes water-table characteristics under *Tamarix pentandra* in central Arizona. Water-table fluctuations in 39 ground-water wells within a circular area of about 40 feet in diameter are discussed before and after vegetation removal. Pumping tests to simulate natural diurnal fluctuations in selected wells were not satisfactory. ET losses were not determined.

Phreatophytes occupying many thousand acres of streambanks and flood plains in the Southwest are believed to use huge quantities of water. For management purposes, we would like to know evapo-transpiration (ET) rates and amounts for various species and associations.

Scientists[2,3,4,5] have approached the study of ET in various ways. The formula used by White[2] and later modified by Gatewood et al.[3] to determine ET losses from diurnal fluctuation data assumes water is withdrawn by ET uniformly over an area containing phreatophyte species and that the well site is an unbiased sample of a larger area. In tamarisk (Tamarix pentandra Pall.) or any flood plain vegetation type containing mixed species of differing age, water withdrawal from the capillary fringe or water table is undoubtedly not uniform. Theis and Conover[4] proposed a system of actually measuring the amount of water involved in diurnal fluctuations of a water table. They suggested a line of observation wells be established and calibrated in a study plot; after calibration, the vegetation would be removed, and water-level measurements continued until sufficient data were collected for an analysis. Then, diurnal fluctuations prevailing before vegetation removal might be approximated by withdrawal of water by several small pumps. Discharged water would approximate water used by plants before their removal.

[1]*Associate Range Scientist and Associate Botanist, located at Tempe, in cooperation with Arizona State University; central headquarters are maintained at Fort Collins, in cooperation with Colorado State University*

[2]*White, Walter N. A method of estimating ground-water supplies based on discharge by plants and evaporation from soil--results of investigations in Escalante Valley, Utah. U. S.Geol. Survey Water-Supply Paper 659, 105 pp., illus. 1932.*

[3]*Gatewood, J. S., Robinson, T. W., Colby, B. R., and others. Use of water by bottom-land vegetation in lower Safford Valley, Arizona. U. S. Geol. Survey Water-Supply Paper 1103, 210 pp., illus. 1950.*

[4]*Theis, C. V., and Conover, C. S. Factors for consideration in study of salvage of water used by phreatophytes. App. IV. Mimeographed report to the Salt Cedar Interagency Council by Salt Cedar Interagency Task Force. Albuquerque, N. Mex., Feb. 1959.*

[5]*Decker, J. P., Gaylor, W. G., Cole, F. D. Measuring transpiration of undisturbed tamarisk shrubs. Plant Physiol. 37: 393-397, illus. 1962.*

The primary objective of the study reported here was to evaluate the pumping technique for measuring ET losses from tamarisk. The following factors were determined: (1) degree of diurnal fluctuation of a shallow water table beneath a tamarisk stand, (2) effect of tamarisk removal on water-table fluctuations, and (3) whether diurnal fluctuations in a relatively small area could be simulated by pumping with sump pumps.

Study Area and Instrumentation

The study area was located east of Granite Reef Diversion Dam on a flood plain of the Salt River in central Arizona. Relatively constant river stage is maintained during spring and summer months, but by late fall the river is dry and ground-water levels drop 2 feet or more. All pumping tests and measurements of diurnal fluctuations were in a relatively mature tamarisk stand. The trees averaged 25 feet in height and contained 190 square feet (1 foot aboveground) of basal area per acre. Soil beneath the plot was mainly alluvial deposits of silty sand in the first 3 to 4 feet, grading into coarse sand and gravel to an unknown depth. Granite bedrock underlaid the entire flood plain.

Eight 8-inch wells were irregularly spaced around an FW-1 water-stage recorder-equipped well at distances ranging from 6 to 7 feet (fig. 1). Thirty 3-inch wells were asymmetrically located from 2.2 to 20 feet from the center FW-1 well. A control, recorder-equipped 8-inch well was located approximately 150 feet from the cluster of pumping wells. Vegetation on the site prevented uniform spacing of well casings. All wells except the recorder well were instrumented with a float and tape device [6] for measuring water-table fluctuations. Changes in water-table levels were detectable to the nearest 0.005 foot. Water levels during the study period were approximately 4 feet below the soil surface with water-table slope negligible. The entire length of all well casings was perforated.

[6] *Gary, Howard L. A simple device for measuring fluctuations in shallow ground-water wells. U. S. Forest Serv., Rocky Mountain Forest and Range Expt. Sta. Res. Note 68, 2 pp., illus. 1961.*

Figure 1.--Location and spacing of wells around the recorder-equipped well.

Diurnal Fluctuations

Continuous records of water-table depths during 1961 and 1962 show that diurnal fluctuations begin in early April, reach their highest cycle in July, then slowly decrease in magnitude through September, and usually stop in October when tamarisk loses its leaves (fig. 2).

It is commonly assumed that a water table in a relatively small area is level or slopes uniformly in one direction, and that diurnal fluctuations are essentially the same within a small area. Because of these assumptions, many earlier studies have been characterized by inadequate numbers of sampling points to determine water-table fluctuations. Data from 39 ground-water wells (fig. 1) within an area of approximately 0.028 acre show that the water table is not a smooth plane at any given time. The variability of water level was demonstrated on several occasions during times

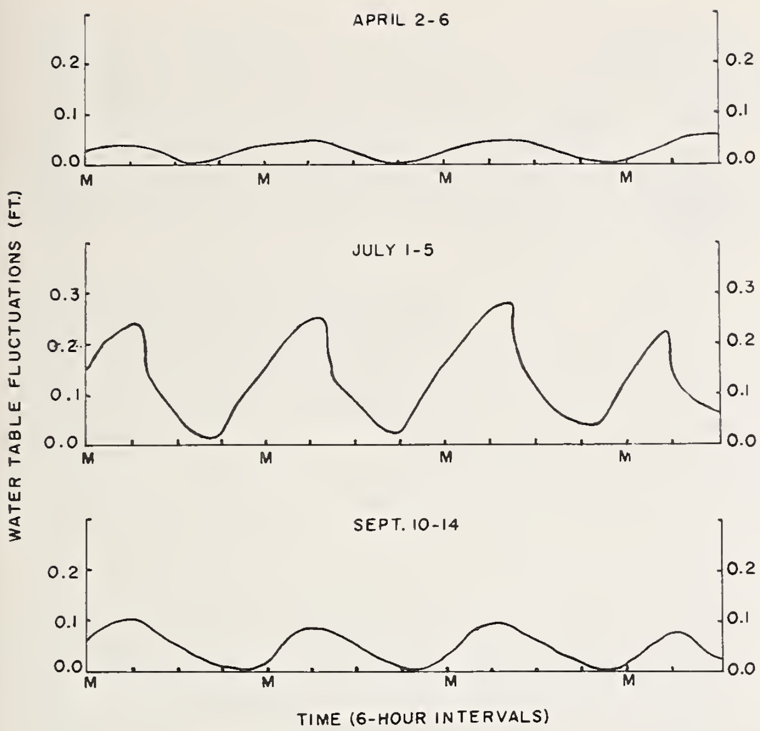


Figure 2.--Tracings from FW-1 recorder equipped well showing the water-table fluctuations in spring, summer, and fall months near Granite Reef Diversion Dam, central Arizona.

of maximum plant growth and diurnal fluctuations. By first obtaining values from the float and tape devices in each well (readings required about 5 minutes) and by careful use of a transit, rod, and measuring tape, near simultaneous readings of water-table levels were possible. All tests showed about the same variability among wells, but no consistent relationship between any two wells. In one test on June 6, 1964, range of variation was 0.235 foot. Standard deviation(s) about the mean (0.109 ft.) from a common datum was 0.043 foot, which illustrates the variability in water-table elevation when the area was intensively sampled. Thus, the water table at any given time may be projected as an irregular surface when plants are actively transpiring.

Measurements of daily water-table depletion in the 39 wells also indicated nonuniform changes in water levels. A test conducted at 30-minute intervals (table 1) shows greatest variability between wells occurred during the first 3 hours following start of water-table depletion and again near the time of water-table rise.

Table 1.--Water-level decline in 39 wells at 30-minute intervals and resulting sampling errors,[1] July 18, 1961

Time (Hours)	Water-table decline			Sampling error
	Maximum	Minimum	Mean	
	Ft.	Ft.	Ft.	Pct.
0700	--	--	--	--
0730	0.025	0.000	0.007	30.00
0800	.040	.000	.014	17.86
0830	.040	.010	.024	7.92
0900	.040	.015	.026	6.15
0930	.035	.005	.020	9.00
1000	.035	.005	.019	7.37
1030	.025	.010	.016	7.50
1100	.030	.010	.020	10.50
1130	.025	.005	.018	11.11
1200	.020	.005	.012	10.00
1230	.030	.010	.015	8.67
1300	.020	.005	.010	12.00
1330	.020	.005	.010	11.00
1400	.020	.005	.011	11.82
1430	.015	.005	.008	13.75
1500	.015	.000	.007	18.57
1530	.010	-.010	.002	55.00
1600	.005	-.010	.000	--
1630	.010	-.010	.000	--
1700	.000	-.015	-.004	--

[1] Indicate accuracy of 30-minute mean water-table change of 39 wells with probability of 95%; rate of water-table change in 8-inch wells similar to that of 3-inch wells.

Effect of Tamarisk Removal on Ground-Water Fluctuation

In the summer of 1961, tamarisk and arrowweed (Pluchea sericea (Nutt.) Coville) were removed from a nearby area in three stages.[7] Basal area of tamarisk and arrowweed stems averaged 120 square feet per acre. Areas cleared were:

	Radius (Ft.)	Area (Sq.ft.)
First treatment	12.5	491
Second treatment	17.7	984
Third treatment	30.5	2,922

[7] *Gary, Howard L. Removal of tamarisk reduces water-table fluctuations in central Arizona. U. S. Forest Serv., Rocky Mountain Forest and Range Expt. Sta. Res. Note 81, 4 pp., illus. 1962.*

After the initial treatment of 491 square feet, water-table fluctuation, measured by a centrally located recorder well, was significantly decreased in amplitude. No significant additional change resulted from second and third cutting treatments; however, combined treatments significantly reduced diurnal fluctuations.

On August 1, 1962, a similar clearing in tamarisk was made with a 12.5-foot radius (491 sq. ft.) around a recorder-equipped well (fig. 3). Approximately 2.0 square feet of basal area was removed. Contrary to results of the 1961 clearing, a change in diurnal fluctuation did not immediately occur. It was assumed, then, that lateral roots of mature tamarisk growing outside the cleared plot might be drawing water from within. A circular trench 1 foot wide and 4 feet deep, with a 15-foot radius was excavated, lined with polyethylene, and then refilled. Following the trenching, planimetered area of diurnal fluctuations as taken from recorder charts were reduced approximately 46 percent compared to the adjacent control well records. Since no roots were observed below 3 feet, the plants probably were using capillary water. Obervations of the excavated trench showed that capillary moisture extended to the ground surface.

Effect of Pumping on Water-Level Elevations

All pumping tests described were conducted on the site before vegetation removal to determine applicability of the sump pump technique and effects of pumping on water-level elevations. After vegetation removal on August 1, 1962, pumping tests were continued; however, the area soon flooded, and the wells filled with sediment and debris so pumping operations were discontinued.

Eight 8-inch wells surrounding the recorder-equipped well were used to determine possibility of influencing natural diurnal fluctuations before vegetation removal. Each 8-inch well was equipped with a small 1/70 h.p. electric sump pump that could be raised or lowered to desired depths and a float and tape device to obtain a measure of well drawdown (fig. 3). On some occasions the recorder-equipped well was similarly instrumented. In every pumping test, pumps were operated continuously at one predetermined elevation although flow rates of individual pumps varied with the hydraulic heads and transmissibility of flood plain deposits surrounding each well.

Many combinations of pumping tests were undertaken in wells P1-P9 at heads from 0.200 to 2.500 feet. During one pumping test conducted July 13, 1962, the water level in nine wells (P1-P9) was lowered as far as possible with the small pumps and maintained at approximately that level for 24 hours. Hydraulic gradients of more than 2 feet were maintained in each well being pumped. The steep gradients created by pumping did not appreciably influence water levels in the adjacent 3-inch observation wells, however, even after pump-

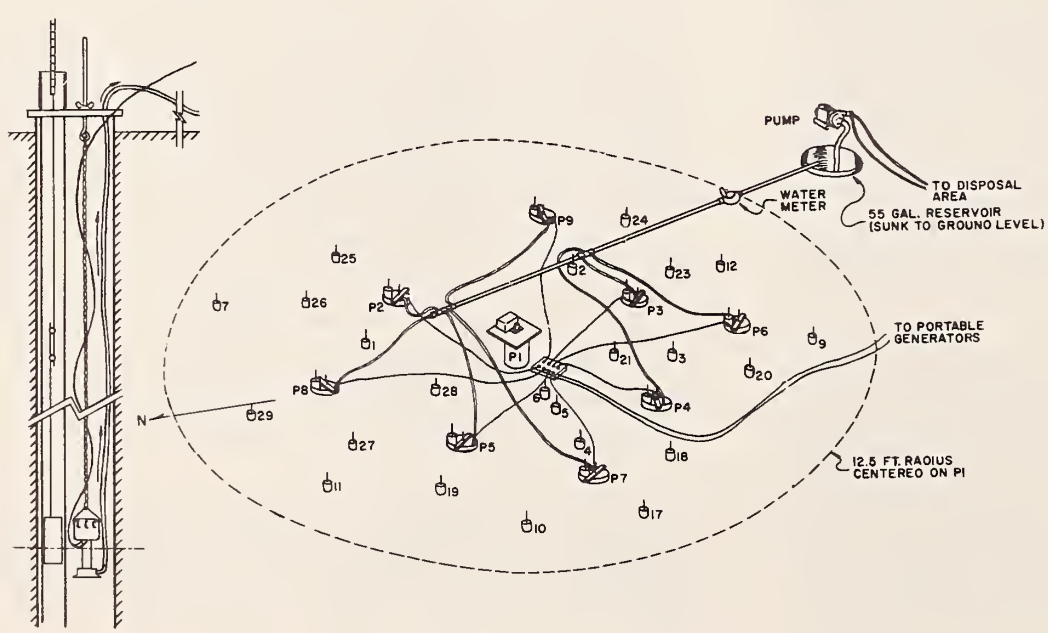
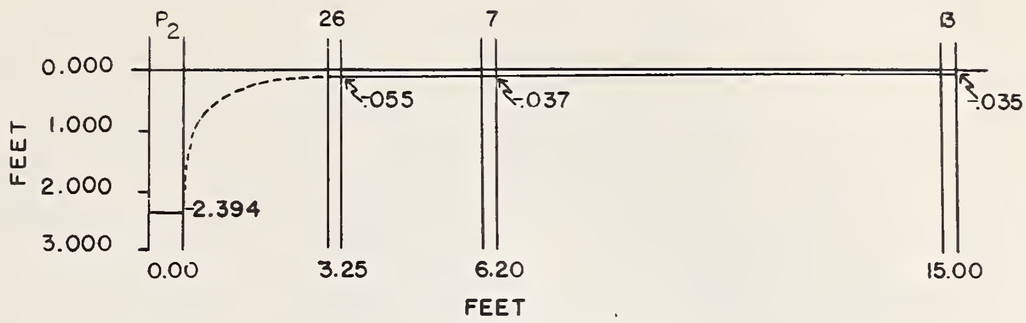


Figure 3. -- Isometric drawing of the pumping area and system used to remove the ground water. Dotted line shows the area cleared of vegetation. Enlarged section shows float and staff gage inside a 3-inch casing and sump pump mechanism in an 8-inch casing installed with pumps while the numbers 1-29 were the 3-inch observation wells.

Figure 4.--Cross section through wells P2, 26, 7, and 13 showing water-table profile before and after 24 hours of pumping from P1-P9. Dotted line indicates probable slope of water table between P2 and number 26. Approximately 1,000 gallons of water were removed from nine wells. Pumping began at 0940 hours, July 13, 1965.

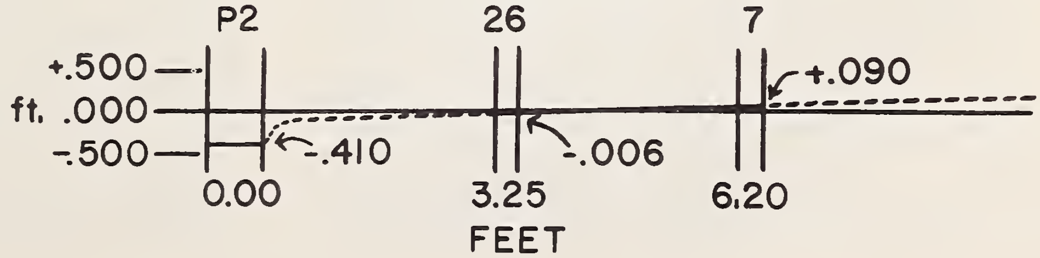


ing approximately 1,000 gallons of water from the nine wells. Water-table drawdown in one of the nine wells after 24 hours of pumping is shown in cross section in figure 4. Water level was apparently affected very little beyond a distance of 3 feet from any of the wells being pumped.

In another pumping test starting at 1700 hours and ending at 2305 hours June 22, 1962, eight pumps were used in wells P2-P9 to lower water table approximately 0.500 foot. Approximately 5 minutes elapsed before pumps lowered the water in well casings 0.500 foot below initial water-table level. Due to mechanical difficulties, water in well P9 was not lowered until 2030 hours. Water table level in well P2 and two nearby wells after the 6-hour period of night pumping is shown in figure 5. Well number 26 was a minus 0.006 foot below and well number 7 plus 0.090 foot above initial water level, which indicated normal rate of evening water table rise exceeded rate of water removal by pumping. Approximately 565 gallons of water were removed during this pumping run. Figure 6, which shows contour lines representing interpretations of water levels between well points at 2000 and 2300 hours, indicates transmissibility of flood plain deposits vary considerably in the relatively small area. Because obvious soil heterogeneity occurs in the pumping area, calculations of transmissibility were not attempted. In figure 6 the 2000 hours water level in P1 is shown as minus 0.041 foot as a result of pumping in wells P2-P9, but by 2300 hours water in P1 had raised to plus 0.012 foot. The minus 0.025-foot contour at 2300 hours indicates how night recharge affects the water table within the area being pumped.

None of the pumping tests influenced natural diurnal fluctuations. It was necessary to create a hydraulic gradient many times that of average diurnal fluctuations (0.250 foot) before the effects of water removal could be

Figure 5.--Cross section through wells P2 - P7 showing the water-table profile before and after 6 hours of night pumping. Dotted line indicates the probable water-table profile. Approximately 565 gallons of water were removed from wells P2 - P9.



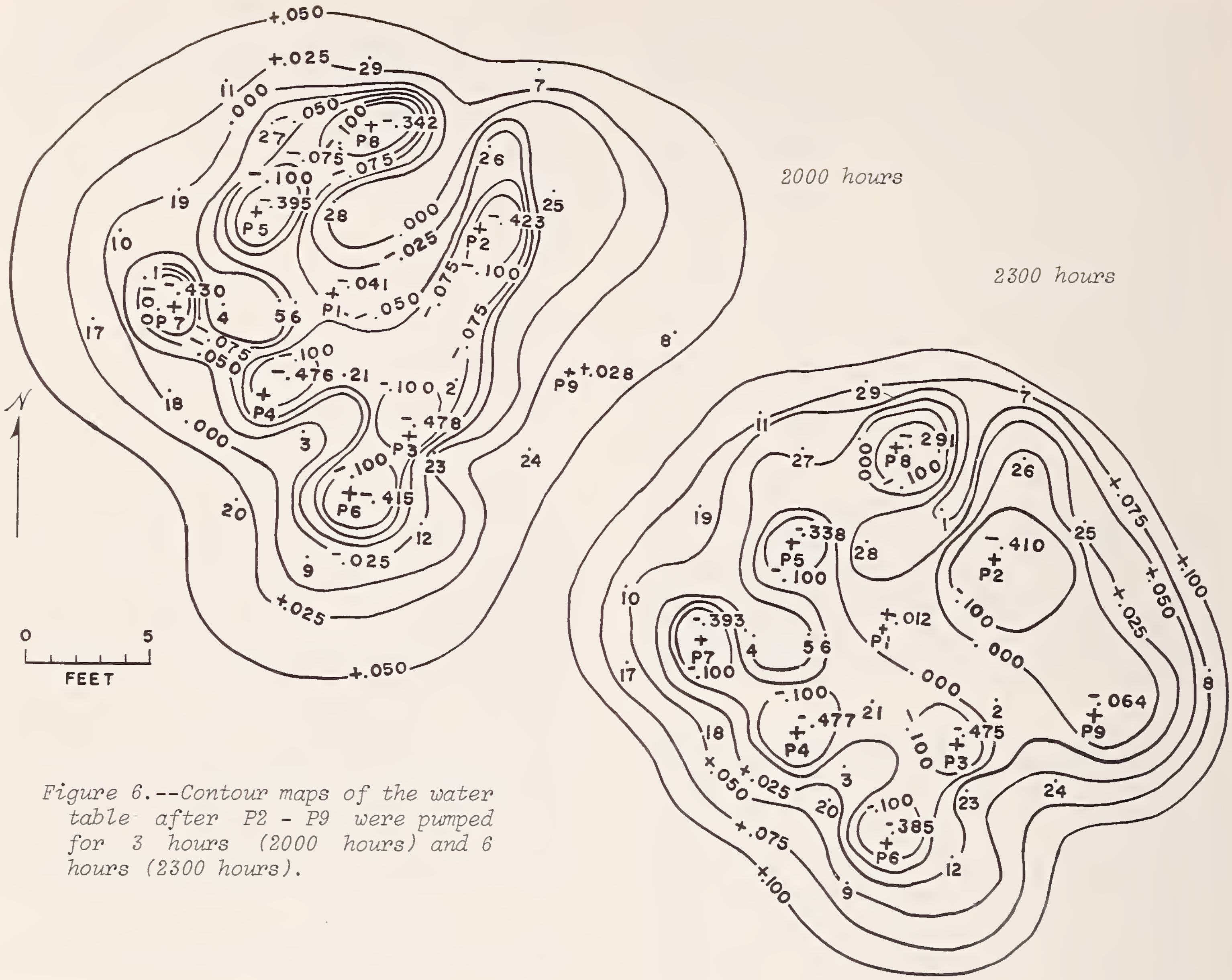


Figure 6.--Contour maps of the water table after P2 - P9 were pumped for 3 hours (2000 hours) and 6 hours (2300 hours).

detected in adjacent observation wells. Well casings were not clogged, because water could be seen pouring through perforations.

Discussion

Diurnal Fluctuations

Simultaneous measurements of water-table elevations in 39 wells within a 40-foot circular area showed considerable variation among wells. During one observation period, a maximum difference of 0.235 foot was indicated. Rates of water-table decline differed during all measurement periods. Greatest difference in daily rates of water-table depletion between wells was near start of decline and just before beginning of water-table rise.

Many factors influence the diurnal fluctuation of a shallow water table--age, structure, species or associations, temperature, atmospheric pressure, relative humidity, soil genesis, relative height of the water table and slope, and hydraulic conductivity of water-bearing material. Also, the unequal distribution and physiologic activity of roots in the capillary fringe above a shallow water table result in variable water use by plants. Diurnal water-table fluctuations are reduced following the removal of flood plain vegetation. The amount of reduction depends on interaction of the above-mentioned factors. Considerably more work is needed to fully assess the effect of each variable.

Vegetation Removal

It has been recognized that, at points in an area, the amplitude of a diurnal fluctuation varies with the porosity (specific yield) of the material in which the fluctuation occurs--assuming ET losses occur uniformly over an area. If, however, withdrawal of water by plants does not occur uniformly over an area, the pumping technique is even more difficult to apply. Reference here is to the variation in ET--not in the variation measured in amplitude of the diurnal fluctuations. In any floodplain vegetation type, however, withdrawal from the capillary fringe is undoubtedly not uniform throughout a given area. The question arises: where should the wells be located to give an unbiased estimate of average rate and amount of ET losses for a plant or land area? The variability of diurnal fluctuations measured in a relatively small area with vegetation in place is evidence that results from such a well may be totally erroneous.

Pumping to simulate natural diurnal fluctuations was unsuccessful. The creation of small hydraulic heads in eight wells within an 8-foot radius did not appreciably lower the surrounding water table although a considerable amount of water was pumped from each well. Water movement in adjacent wells was never apparent except under hydraulic heads of more than 1 foot. It seems doubtful that pumps can be used successfully to simulate natural water-table depletions caused by ET from phreatophytes, even if well locations are unbiased and ET losses uniformly distributed. A basic difference between the pumping action on water-table drawdown and depletions caused by ET losses is that pumps remove free water from well casings stemming from the surrounding coarse gravel layers, while plant roots primarily draw water from the capillary fringe. As water is removed from the capillary fringe by vegetation, vertical recharge occurs from the water table beneath. It is only after ET losses decrease in the evening that excess recharge water can eliminate the moisture deficit created by vegetation each day.

Summary

Good estimates of ET losses from tamarisk on the site of the present study were not obtained with the pumping technique outlined by Theis and Conover.[4] Diurnal fluctuations of water tables were extremely variable between any two wells because of heterogeneous plant and soil conditions. Diurnal fluctuations were decreased by removal of vegetation on a small area and by elimination of roots from surrounding vegetation by trenching, but the amount of decrease was not predictable. Pumping removed ground water from well casings, but did not appreciably influence water levels in adjacent wells.

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